1. Natural Gas + Renewable Reciprocating Engine Technology and 2. Hybrid Recip + Gas Turbine

Presented by

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Natural Gas/Renewable Energy Hybrids Workshop

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Two Areas of Discussion

- Combining NG and Renewable
- Hybrid Recip + GT
- Meeting Goals Identified by Rita
  - Improve Component Efficiency
  - Introduce Practical Renewables
  - Improve System Efficiency
  - Reduce Emissions

Natural Gas + Renewable Reciprocating Engine Technology

ARES Overview

(*Advanced Reciprocating Engine System)*

Program Members - Update

- Department of Energy
- Gas Research Institute
- Caterpillar
- Cooper Energy Services
- Waukesha Engine Division
- Southern California Gas Company
- Altronic
- Woodward
- Champion Ignition Products

Project Objectives

- Identify and Develop Technology Required for High Efficiency and Low Emissions in NG Recips
- Efficiency Target: 50% BTE
- NO_x Emissions Target 5 ppm

Barriers to High Efficiency

- Knock
- Combustion efficiency
- Combustion rate
- In-cylinder heat loss
- Frictional losses
- Pumping losses
- Exhaust port and manifold heat loss
- Efficient exhaust energy recovery
- Structural limitation
- NO_x emission

Likely Approaches

- Lean Air-Fuel Ratio

  or

- High EGR Stoichiometric Air-Fuel Ratio
- High Specific Power (High BMEP)
- Exhaust Energy Recovery

Barriers to High Efficiency (Affected by Ignition)

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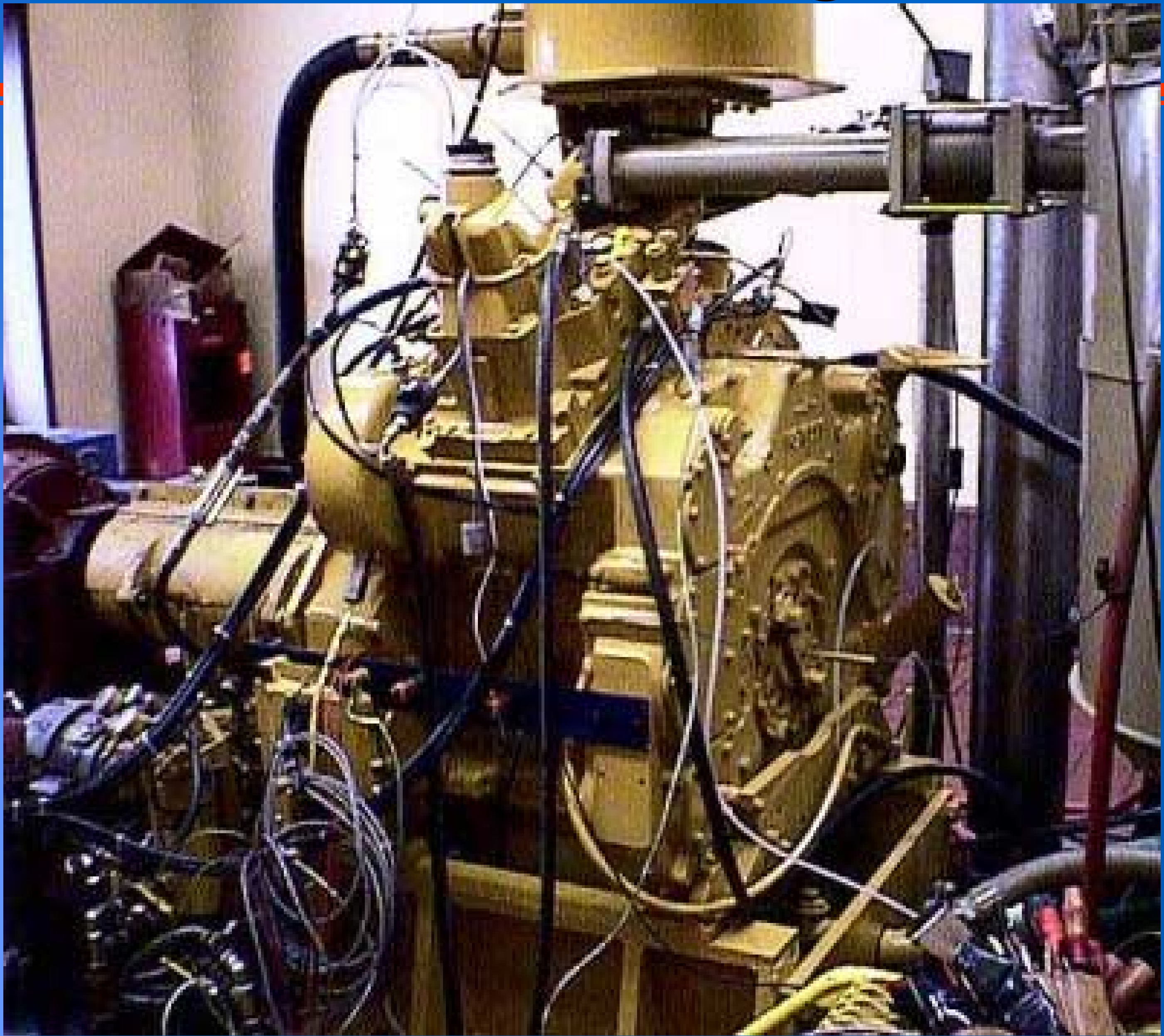
Funded Tasks

- Virtual Engine (Technical Path)
- High BMEP Engine Development
- Knock Mitigation Modeling
- Detailed Knock Kinetics
- Ignition System Development
  - Micro-Pilot Ignition
- Direct In-cylinder Water Injection
- Exhaust Aftertreatment
- Turbocompounding

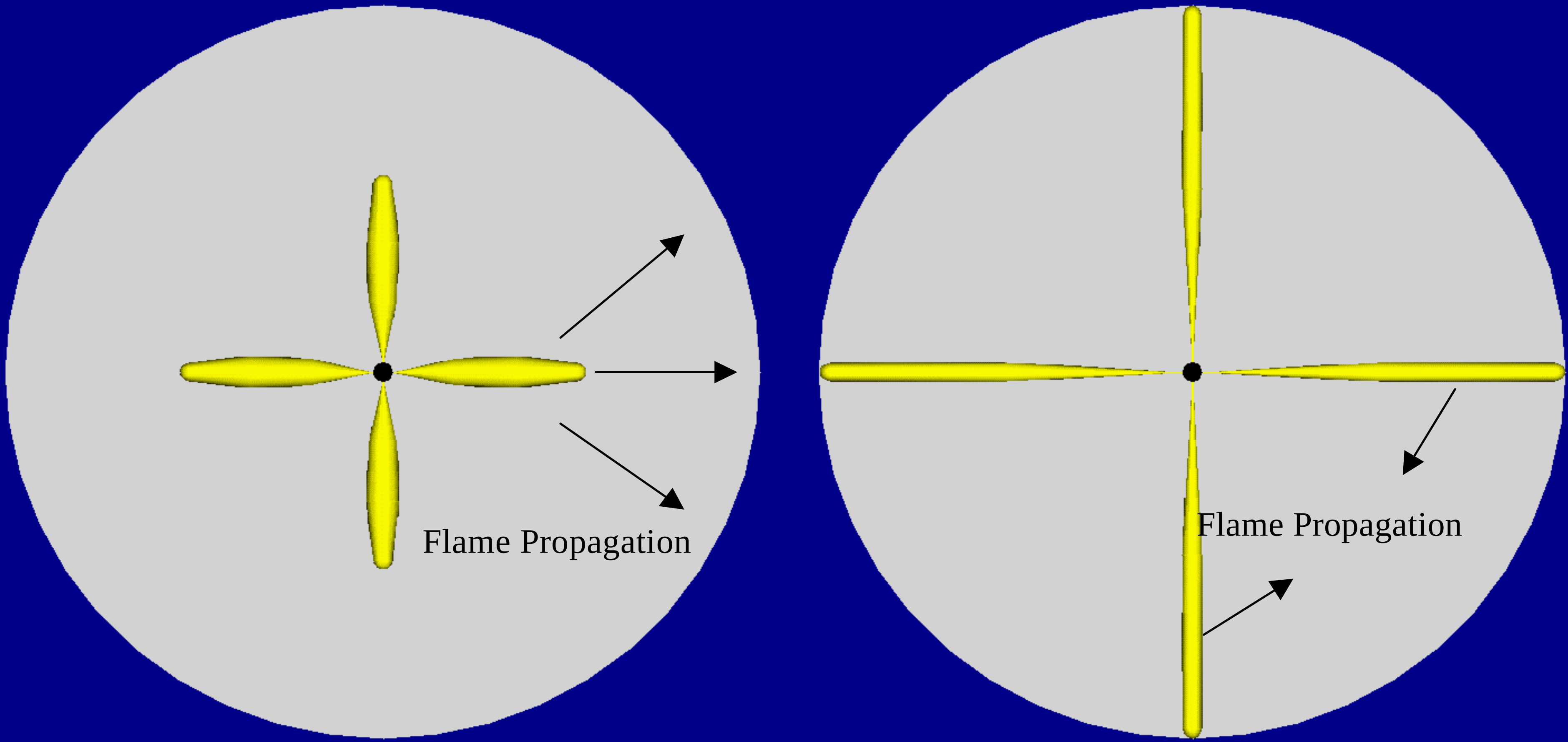
3501G Test Engine



MicroPilot Background

- Pilot ignition can provide improved performance and lower NO_x emissions
- Most successfully implemented with a prechamber system
- Suspect open chamber configurations limited by injection system and that with an optimized injection system, open chamber systems can exceed performance of prechamber systems

Illustration of Open Chamber Pilot Ignition Concept



Low injection pressure poor penetration

High injection pressure good penetration

Injection System Requirements for Open Chamber Pilot Ignition

- Pressure independent of engine speed and load
- Flexible injection timing
- Sharp start and end of injection
- Injection pressure ~ 100 MPa
- Nozzle hole diameter < 0.15 mm
- Injection quantity ~ 8 mm^3
- Injection duration ~ 2 CAD

Fuel Requirements
for Open Chamber Pilot Ignition

- Low Auto Ignition Temperature
- High Cetane Number
- Density Similar to DF2
- Viscosity Similar to DF2
- High Hydrogen to Carbon Ratio
  - Reduced NOx
  - Reduced PM
- Oxygenated

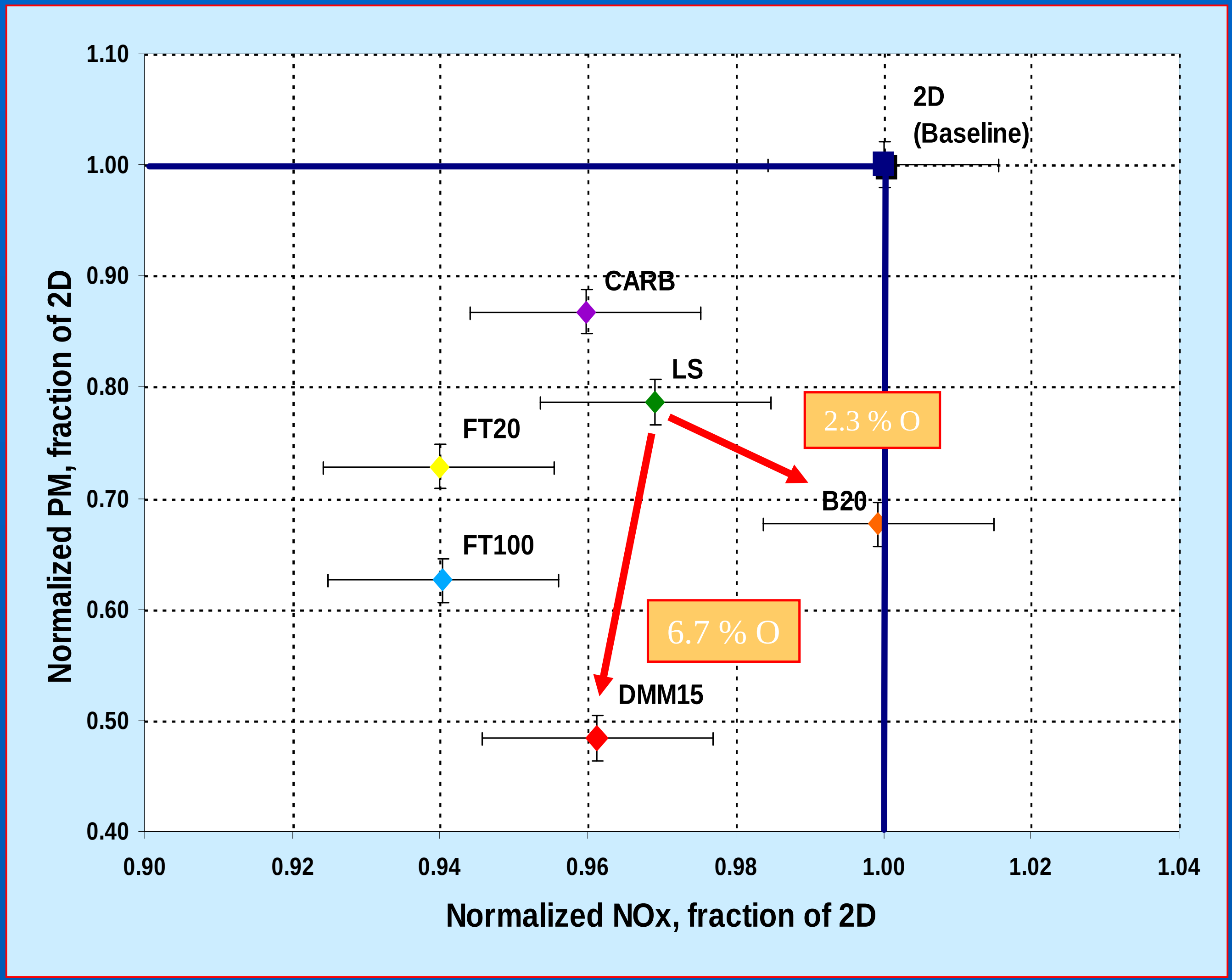
Potential Fuels

- Biodiesel
  - Renewable
  - Correct Properties
  - Available in Correct Quantities
- Synthetic from Biomass
  - Optimized for Application
  - Potentials (from other DOE programs?)

Questions

- What is the Optimum Pilot Fuel?
- Is Biodiesel Good Enough?
  - Quantities Required for Ignition
    - Economics
    - Availability
    - Emissions
- Can an Optimum Pilot Fuel be Made from Biomass?

Demonstrated Benefits



Hybrid Recip + Gas Turbine

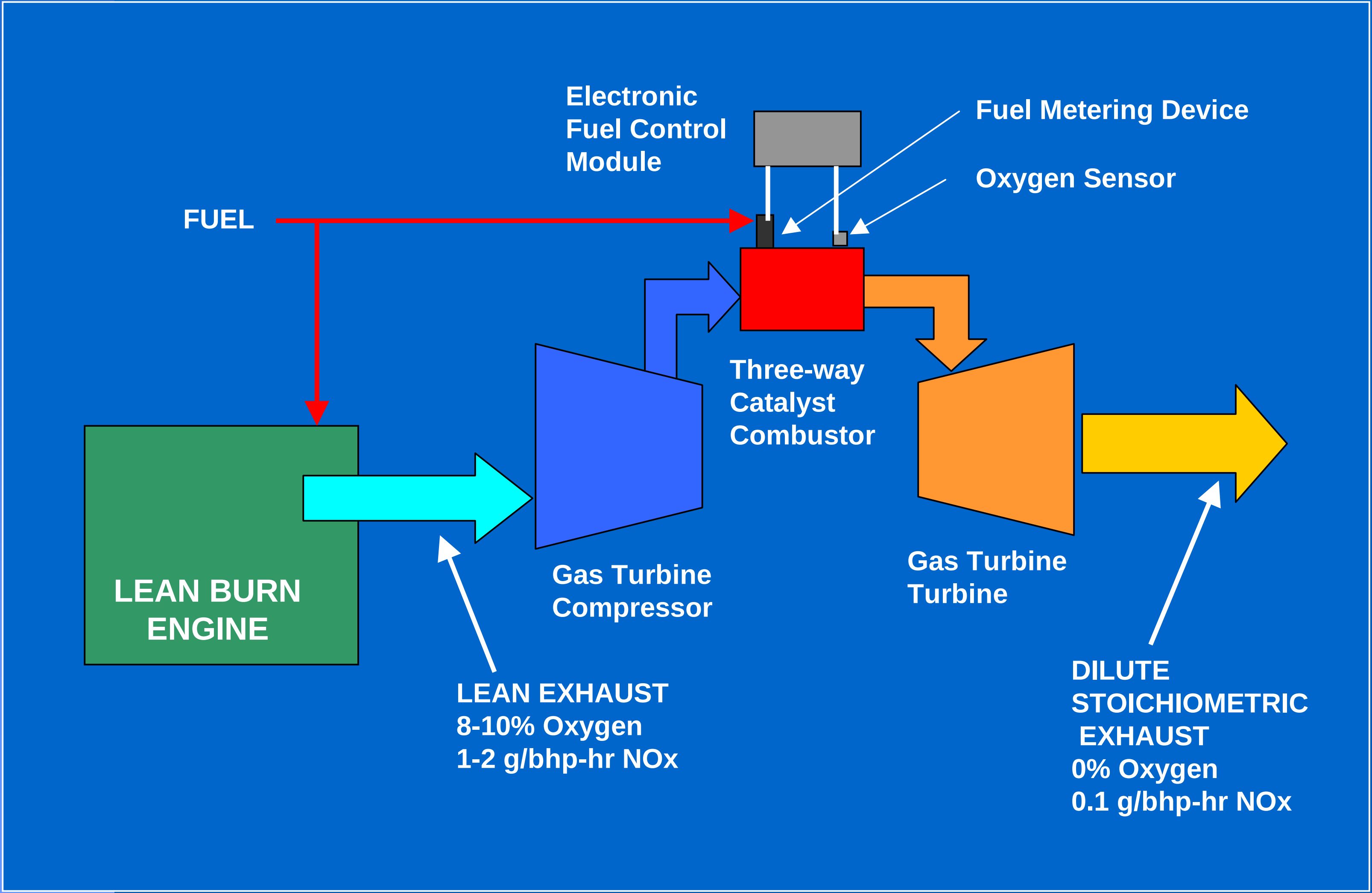
Background

- Lean Natural Gas Reciprocating Engines Give Low Engine Out Emissions and High Efficiency
  - Additional NOx Reduction Through After Treatment is Difficult
- Catalytic Combustors in Gas Turbines Give Ultra Low Emissions

Approach

- Combine Lean Reciprocating Engine with a Gas Turbine
- Lean Exhaust Goes to Compressor in Gas Turbine, Then to a Catalytic Combustor with more Fuel to Stoichiometric, to Turbine
- Shaft Power Combined Mechanically, Electrically, or Hydraulically

Hybrid Recip + Gas Turbine



Questions

- Can Lean Exhaust (~9% O_2) be Used in the Catalytic Combustor?
- Can the Catalytic Combustor Include a NOx Reduction Element - Similar to 3-Way Catalyst?
- Can the Engine Control and Fuel Control for the Combustor be Integrated for High Efficiency and Low Emissions?
- What is the Best Mechanism for Coupling the Outputs?